CLAIMS

What is claimed is:

1. A reflection-type optical circulator, comprising:

at least one birefringent plate for receiving at least one signal light ray from a first port; and

a mirror optically coupled to the at least one birefringent plate, wherein the mirror and the at least one birefringent plate causes the at least one signal light ray to be folded back upon itself, wherein the at least one signal light ray is directed to a second port.

2. The circulator of claim 1, wherein the at least one birefringent plate comprises:

a first birefringent plate, wherein the first birefringent plate separates the at least one signal light ray into a plurality of sub-signal rays; and

a second birefringent plate optically coupled to the first birefringent plate.

3. The circulator of claim 2, further comprising:

at least one optical rotator optically coupled between the first and second birefringent plates, wherein the at least one optical rotator intercepts a portion of the plurality of sub-signal rays;

at least one reciprocal optical rotator and at least one non-reciprocal optical rotator optically coupled to the second birefringent plate at a side opposite to the at least one optical

at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator optically coupled to the polarization beam-splitter at a side opposite to the optical rotator; and

a lens optically coupled to the at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator at a side opposite to the polarization beam-splitter.

24. The system of claim 23, wherein the mirror is optically coupled to the lens at a side opposite to the at least one reciprocal rotator.

25. The system of claim 23, wherein the beam-turning reflector turns a direction of propagation of a light ray propagating therethrough by 90 degrees.

26. The system of claim 23, wherein the polarization beam splitter deflects a portion of a light ray propagating therethrough by 90 degrees.

27. The system of claim 23, wherein the at least one reciprocal optical rotator rotates a polarization plane direction of a light ray propagating therethrough by 45 degrees and wherein the at least one non-reciprocal optical rotator non-reversibly rotates a polarization plane direction of a light ray propagating therethrough by 45 degrees.

28. A reflection-type optical circulator, comprising:

a first birefringent plate for receiving at least one signal light ray from a first port,

wherein the first birefringent plate separates the at least one signal light ray into a plurality of sub-signal rays;

a second birefringent plate optically coupled to the first birefringent plate;

at least one optical rotator optically coupled between the first and second birefringent plates, wherein the at least one optical rotator intercepts a portion of the plurality of sub-signal rays;

at least one reciprocal optical rotator and at least one non-reciprocal optical rotator optically coupled to the second birefringent plate at a side opposite to the at least one optical rotator;

a lens optically coupled to the at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator at a side opposite to the second birefringent plate; and

a mirror optically coupled to the lens at a side opposite to the at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator,

wherein the mirror reflects the plurality of sub-signal rays such that the plurality of sub-signal rays is folded back upon itself,

wherein the at least one reciprocal optical rotator, the at least one non-reciprocal optical rotator, the at least one optical rotator, and the first and second birefringent plates recombine the reflected plurality of sub-signal rays into the at least one signal light ray, such that the recombined at least one signal light ray is directed to a second port.

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~~29~~. A reflection-type optical circulator, comprising:

a birefringent plate for receiving at least one signal light ray from a first port,

wherein the birefringent plate separates the at least one signal light ray into a plurality of sub-signal rays;

an optical rotator optically coupled to the birefringent plate, wherein the optical rotator intercepts a portion of the plurality of sub-signal rays;

a beam-turning reflector optically coupled to the birefringent plate and to the optical rotator at a side opposite to the birefringent plate;

a polarization beam-splitter optically coupled to the birefringent plate, the optical rotator at a side opposite to the birefringent plate, and the beam-turning reflector at a side perpendicular to the optical rotator;

at least one reciprocal optical rotator and at least one non-reciprocal optical rotator optically coupled to the polarization beam-splitter at a side opposite to the optical rotator;

a lens optically coupled to the at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator at a side opposite to the polarization beam-splitter; and

a mirror optically coupled to the lens at a side opposite to the at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator,

wherein the mirror reflects the plurality of sub-signal rays such that the plurality of sub-signal rays is folded back upon itself,

wherein the at least one reciprocal rotator, the at least one non-reciprocal rotator, the polarization beam-splitter, the beam-turning reflector, the optical rotator, and the birefringent plate recombine the reflected plurality of sub-signal rays into the at least one signal light ray, such that the recombined at least one signal light ray is directed to a second port.

30. A reflection-type optical circulator, the optical circulator having four ports, comprising:

a first birefringent plate for receiving a plurality of signal light rays from the four ports, wherein the first birefringent plate separates the plurality of signal light rays into a plurality of sub-signal rays;

a second birefringent plate optically coupled to the first birefringent plate, wherein a thickness and optical orientation of the second birefringent plate is chosen so as to provide an offset in a direction of a sub-signal ray propagating therethrough by a distance equivalent to a common center-to-center inter-port separation distance;

a first and a second 90 degree optical rotator each optically coupled between the first and second birefringent plates, wherein the first and second 90 degree optical rotators each intercept a portion of the sub-signal rays from two of the four ports;

a 45 degree reciprocal optical rotator optically coupled to the second birefringent plate at a side opposite to the first and second 90 degree optical rotators, wherein the 45 degree reciprocal rotator intercepts the sub-signal rays from two of the four ports;

a 45 degree non-reciprocal optical rotator coupled to the second birefringent plate at a side opposite to the first and second 90 degree optical rotators, wherein the 45 degree non-reciprocal optical rotator intercepts the sub-signal rays from two of the four ports;

a lens optically coupled to the 45 degree reciprocal optical rotator and the 45 degree non-reciprocal optical rotators at a side opposite to the second birefringent plate; and

a mirror optically coupled to the lens at a side opposite to the 45 degree reciprocal optical rotators and the 45 degree non-reciprocal optical rotator,

wherein the mirror reflects the plurality of sub-signal rays such that the plurality of sub-signal rays is folded back upon itself,

wherein the 45 degree reciprocal optical rotator, the 45 degree non-reciprocal optical rotator, the first and second 90 degree optical rotators, and the first and second birefringent plates recombine the reflected plurality of sub-signal rays into the plurality of signal light rays, such that the recombined plurality of signal light rays are each directed to a different port from which it was received by the first birefringent plate.

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31. A reflection-type optical circulator, the optical circulator having four ports, comprising:

a birefringent plate for receiving a plurality of signal light rays from the four ports, wherein the birefringent plate separates the plurality of signal light rays into a plurality of sub-signal rays;

an optical rotator optically coupled to the birefringent plate, wherein the optical rotator intercepts a portion of the plurality of sub-signal rays;

a 90 degree beam-turning reflector optically coupled to the birefringent plate and to the optical rotator at a side opposite to the birefringent plate, wherein the 90 degree beam-turning reflector intercepts the sub-signal rays from two of the four ports;

a polarization beam-splitter optically coupled to the birefringent plate and to the optical rotator at a side opposite to the birefringent plate and to the 90 degree beam-turning reflector at a side perpendicular to the optical rotator, wherein the polarization beam-splitter defects the sub-signal rays from two of the four ports while allowing the sub-signal rays

from the other two of the four ports to propagate therethrough without deflection;

a 45 degree reciprocal optical rotator optically coupled to the polarization beam-splitter at a side opposite to the optical rotator, wherein the 45 degree reciprocal optical rotator intercepts the sub-signal rays from two of the four ports;

a 45 degree non-reciprocal optical rotator optically coupled to the polarization beam-splitter at a side opposite to the optical rotator, wherein the 45 degree non-reciprocal optical rotator intercepts the sub-signal rays from two of the four ports;

a lens optically coupled to the at 45 degree reciprocal optical rotator and the 45 degree non-reciprocal optical rotator at a side opposite to the polarization beam-splitter; and

a mirror optically coupled to the lens at a side opposite to the 45 degree reciprocal optical rotator and the 45 degree non-reciprocal optical rotator,

wherein the mirror reflects the plurality of sub-signal rays such that the plurality of sub-signal rays is folded back upon itself,

wherein the 45 degree reciprocal optical rotator, the 45 degree non-reciprocal optical rotator, the polarization beam-splitter, the beam-turning reflector, the optical rotator, and the birefringent plate recombine the reflected plurality of sub-signal rays into the plurality of signal light rays, such that the recombined plurality of signal light rays are each directed to a different port from which it was received by the first birefringent plate.

32. A method for directing a signal light ray, comprising the steps of:

(a) separating the signal light ray into a plurality of sub-signal rays, wherein the signal light ray is inputted from a first port;

rotator; and

a lens optically coupled to the at least one reciprocal rotator and the at least one non-reciprocal optical rotator at a side opposite to the second birefringent plate.

4. The circulator of claim 3, wherein the mirror is optically coupled to the lens at a side opposite to the at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator.

5. The circulator of claim 3, wherein the at least one optical rotator rotates an orientation of a polarization plane of a light ray propagating therethrough by 90 degrees.

6. The circulator of claim 3, wherein the at least one reciprocal optical rotator rotates a polarization plane direction of a light ray propagating therethrough by 45 degrees and wherein the at least one non-reciprocal optical rotator non-reversibly rotates a polarization plane direction of a light ray propagating therethrough by 45 degrees.

7. The circulator of claim 3, wherein a focal point of the lens is located on the mirror.

8. The circulator of claim 2, wherein a thickness and optical orientation of the second birefringent plate is chosen so as to provide an offset in a direction of a light ray propagating therethrough by a distance equivalent to a common center-to-center inter-port

separation distance.

9. The circulator of claim 1, further comprising:

an optical rotator optically coupled to the at least one birefringent plate, wherein the at least one birefringent plate separates the at least one signal light ray into a plurality of sub-signal rays, wherein the optical rotator intercepts a portion of the plurality of sub-signal rays;

a beam-turning reflector optically coupled to the at least one birefringent plate and to the optical rotator at a side opposite to the at least one birefringent plate;

a polarization beam-splitter optically coupled to the at least one birefringent plate, the optical rotator at a side opposite to the at least one birefringent plate, and the beam-turning reflector at a side perpendicular to the optical rotator;

at least one reciprocal optical rotator and at least one non-reciprocal optical rotator optically coupled to the polarization beam-splitter at a side opposite to the optical rotator; and

a lens optically coupled to the at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator at a side opposite to the polarization beam-splitter.

10. The circulator of claim 9, wherein the mirror is optically coupled to the lens at a side opposite to the at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator.

11. The circulator of claim 9, wherein the optical rotator rotates an orientation of

a polarization plane of a light ray propagating therethrough by 90 degrees.

12. The circulator of claim 9, wherein the beam-turning reflector turns a direction of propagation of a light ray propagating therethrough by 90 degrees.

13. The circulator of claim 9, wherein the polarization beam splitter deflects a portion of a light ray propagating therethrough by 90 degrees.

14. The circulator of claim 9, wherein the at least one reciprocal optical rotator rotates a polarization plane direction of a light ray propagating therethrough by 45 degrees and wherein the at least one non-reciprocal optical rotator non-reversibly rotates a polarization plane direction of a light ray propagating therethrough by 45 degrees.

15. A system for directing a signal light ray, comprising:

an optical network, the optical network comprising the signal light ray; and

a reflection-type optical circulator comprising a plurality of ports, wherein the signal light ray is received at one of the plurality of ports, the reflection-type optical circulator further comprising:

at least one birefringent plate; and

a mirror optically coupled to the at least one birefringent plate, wherein the mirror and the at least one birefringent plate causes the signal light ray to be folded back upon itself, wherein the signal light ray is directed to another of the plurality of ports.

16. The system of claim 15, wherein the at least one birefringent plate comprises:

a first birefringent plate, wherein the first birefringent plate separates the at least one signal light ray into a plurality of sub-signal rays; and

a second birefringent plate optically coupled to the first birefringent plate.

17. The system of claim 16, further comprising:

at least one optical rotator optically coupled between the first and second birefringent plates, wherein the at least one optical rotator intercepts a portion of the plurality of sub-signal rays;

at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator optically coupled to the second birefringent plate at a side opposite to the at least one optical rotator; and

a lens optically coupled to the at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator at a side opposite to the second birefringent plate.

18. The system of claim 17, wherein the mirror is optically coupled to the lens at a side opposite to the at least one reciprocal optical rotator and the at least one non-reciprocal optical rotator.

19. The system of claim 17, wherein the at least one optical rotator rotates an orientation of a polarization plane of a light ray propagating therethrough by 90 degrees.

20. The system of claim 17, wherein the at least one reciprocal optical rotator rotates a polarization plane direction of a light ray propagating therethrough by 45 degrees and wherein the at least one non-reciprocal optical rotator non-reversibly rotates a polarization plane direction of a light ray propagating therethrough by 45 degrees.

21. The system of claim 17, wherein a focal point of the lens is located on the mirror.

22. The system of claim 16, wherein a thickness and optical orientation of the second birefringent plate is chosen so as to provide an offset in a direction of a light ray propagating therethrough by a distance equivalent to a common center-to-center inter-port separation distance.

23. The system of claim 15, further comprising:

an optical rotator optically coupled to the at least one birefringent plate, wherein the at least one birefringent plate separates the signal light ray into a plurality of sub-signal rays, wherein the optical rotator intercepts a portion of the plurality of sub-signal rays;

a beam-turning reflector optically coupled to the at least one birefringent plate and to the optical rotator at a side opposite to the at least one birefringent plate;

a polarization beam-splitter optically coupled to the at least one birefringent plate and to the optical rotator at a side opposite to the at least one birefringent plate and to the beam-turning reflector at a side perpendicular to the optical rotator;

(b) rotating a polarization direction of a portion of the plurality of sub-signal rays;

(c) reflecting the rotated portion and a remainder of the plurality of sub-signal rays, such that the rotated portion and the remainder are folded back upon themselves; and

(d) combining the rotated portion and the remainder of the plurality of sub-signal rays into the signal light ray, wherein the signal light ray is outputted to a second port.

33. The method of claim 32, wherein the separating step (a) and the combining step (d) are performed by at least one birefringent plate.

34. The method of claim 32, wherein the rotating step (b) is performed by at least one optical rotator.

35. The method of claim 32, wherein the reflecting step (c) is performed by a mirror.

36. A system, comprising:

an optical network, comprising a reflection-type optical circulator, the reflection-type optical circulator comprising a plurality of ports; and

a signal light ray traversing through the reflection-type optical circulator,

wherein the signal light ray enters the optical circulator through a first of the plurality of ports,

wherein the signal light ray is separated into a plurality of sub-signal rays,

wherein a polarization direction of a portion of the plurality of sub-signal rays is rotated,

wherein the rotated portion and a remainder of the plurality of sub-signal rays are reflected such that the rotated portion and the remainder are folded back upon themselves, and

wherein the rotated portion and the remainder of the plurality of sub-signal rays are combined into the signal light ray,

wherein the signal light ray is outputted to a second of the plurality of ports.

37. A method for providing a reflection-type optical circulator, comprising the steps of:

(a) providing at least one birefringent plate for receiving at least one signal light ray from a first port; and

(b) optically coupling a mirror to the at least one birefringent plate, wherein the mirror and the at least one birefringent plate causes the at least one signal light ray to be folded back upon itself, wherein the at least one signal light ray is directed to a second port.

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